J/ψ ($\mu^+\mu^-$) Polarization Study from d-Au Collisions at PHENIX/RHIC

Xiaorong Wang

New Mexico State University

for PHENIX Collaboration

QM2004, Oakland CA

Motivation for J/ψ Polarization Study

B.L. Loffe and D.E. Kharzeev:

Hep-ph/0306176: "Quarkonium Polarization in Heavy-ion collision as a possible signature of the QGP"

predicts that an increase of J/ψ polarization in heavy ion collision if the QGP is formed there.

The measurement of the angular distribution of decay leptons from J/ψ provides a detailed test of the production mechanism of the quarkonium bound state.

PHENIX detector has unique ability to study J/ψ production through $\mu^+\mu^-$ and e^+e^- decay channel. In the mean time, it also offer us an opportunity to study J/ψ polarization.

Motivation (Continued)

Theoretical Model Predictions:

- **Quarkonium production cross section**
  - Color Singlet Model (CSM): predicted smaller production rates than observed
  - Color Evaporation Model (CEM): failed in predicting production ratio of $c\,\bar{c}$ states
  - Non-relativistic QCD (NRQCD): using cross section to determine model parameters
- **Quarkonium polarization**
  - CSM: predicts transverse polarization
  - NRQCD: **predicts transverse polarization at large p_T**

Motivation (Continued)

Selected Experimental Observations:

- **Fixed target experiments**
  - **E537, E672, E771:**

    No significant polarization observed.
  - **CIP:**

    Observed no polarization at small x_F and longitudinal polarization at large x_F.
  - **E866:**

    Showed longitudinal polarized at large x_F and no polarization or slight transverse polarized small x_F.
- **Collider experiment** (CDF)

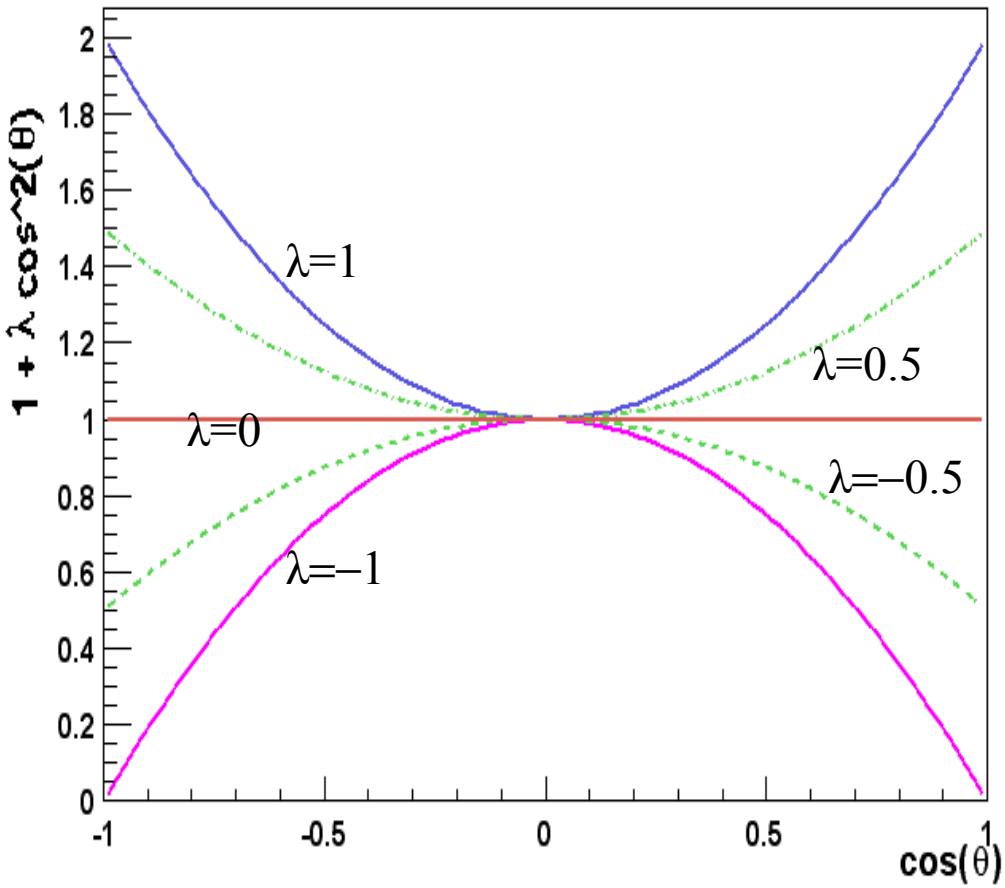
  Observed unpolarized at small p_T and longitudinal polarized at large p_T. This observation can't be explained by NRQCD theory.

Angular Distribution Parametrization

Angular distribution of muon pair in the J/ψ rest frame is commonly parametrized as follows:

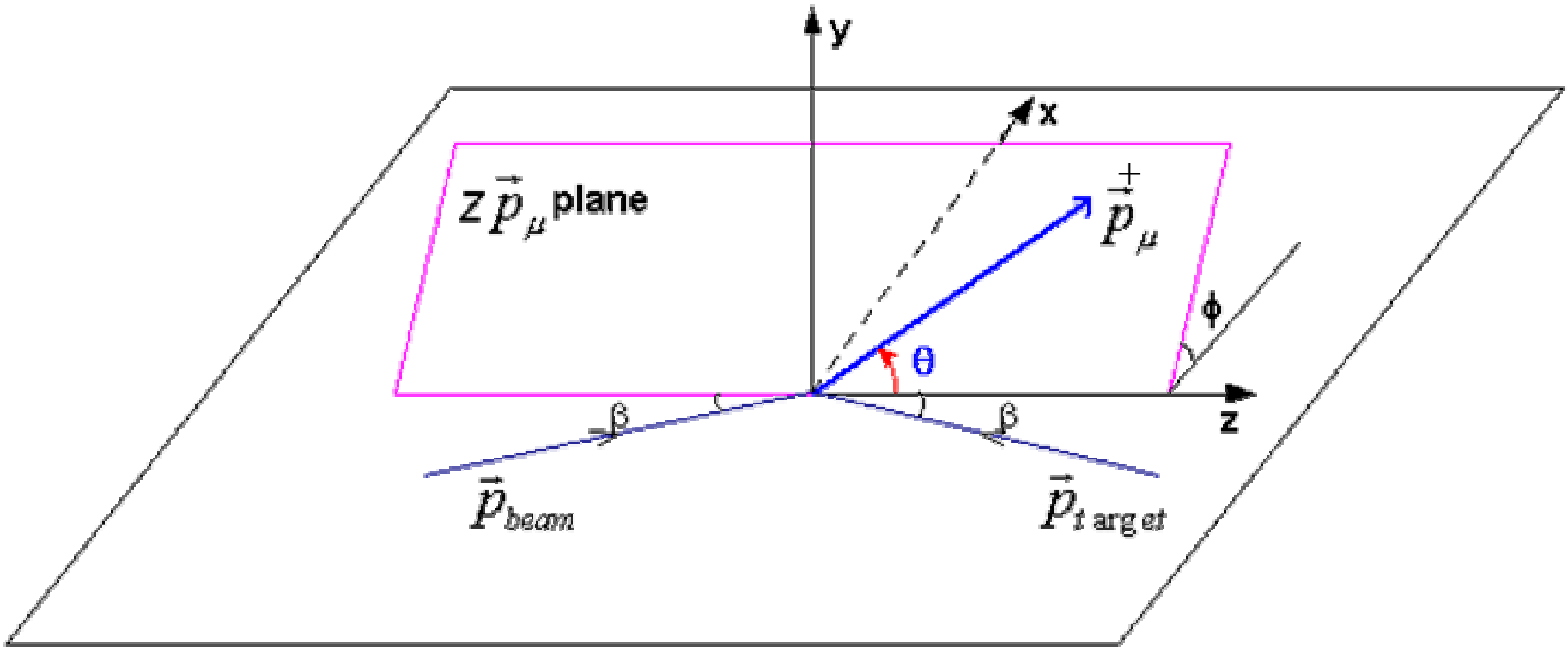
$$\frac{d\sigma}{d\cos\theta} \sim 1 + \lambda \cos^2\theta$$

$\lambda < 0$ Longitudinal
$\lambda = 0$ Unpolarized
$\lambda > 0$ Transverse



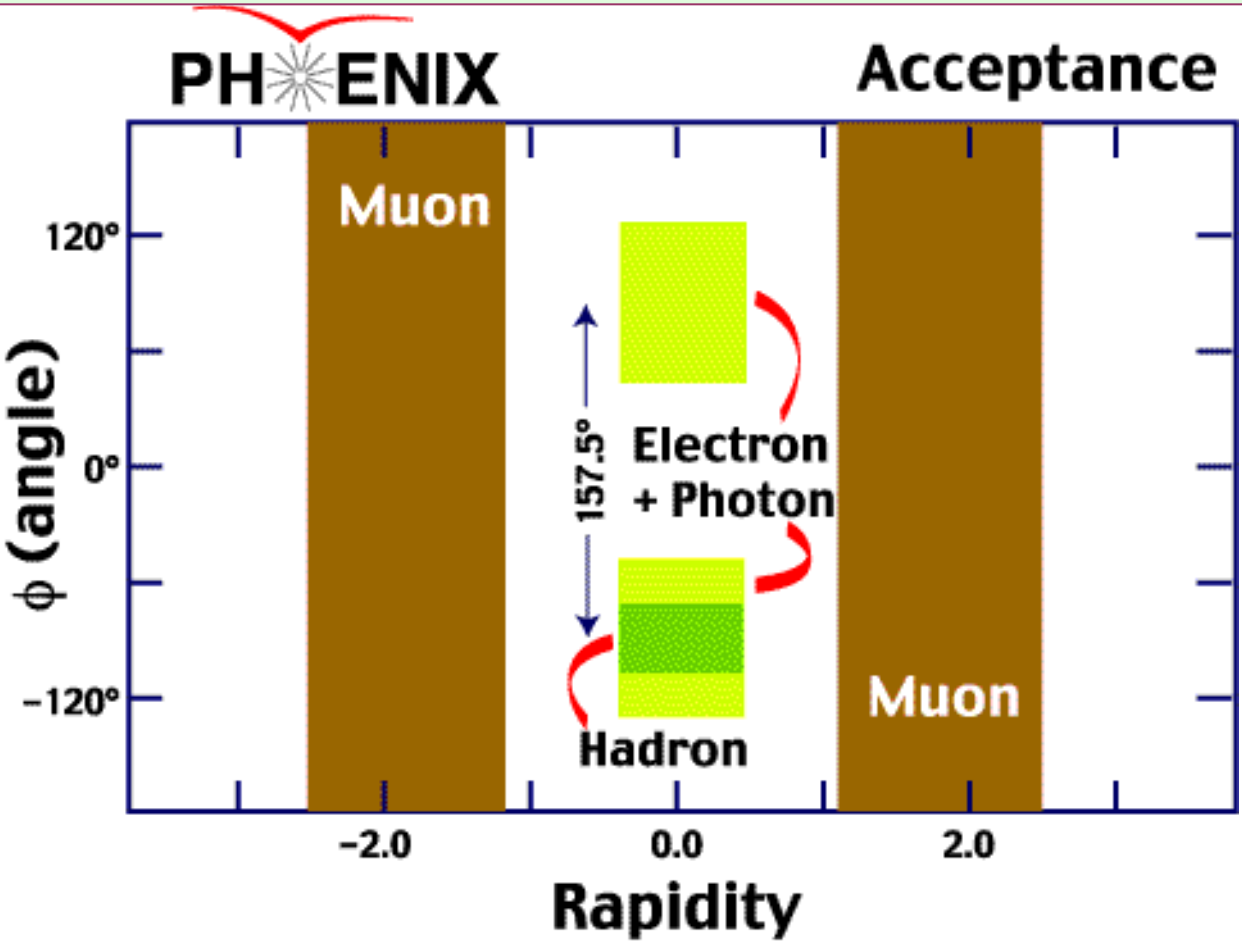
θ is the angle between the $p_{\mu+}$($p_{\mu-}$) and the z axis in the J/ψ rest frame

J/ψ Rest Frame (Collins-Soper frame)



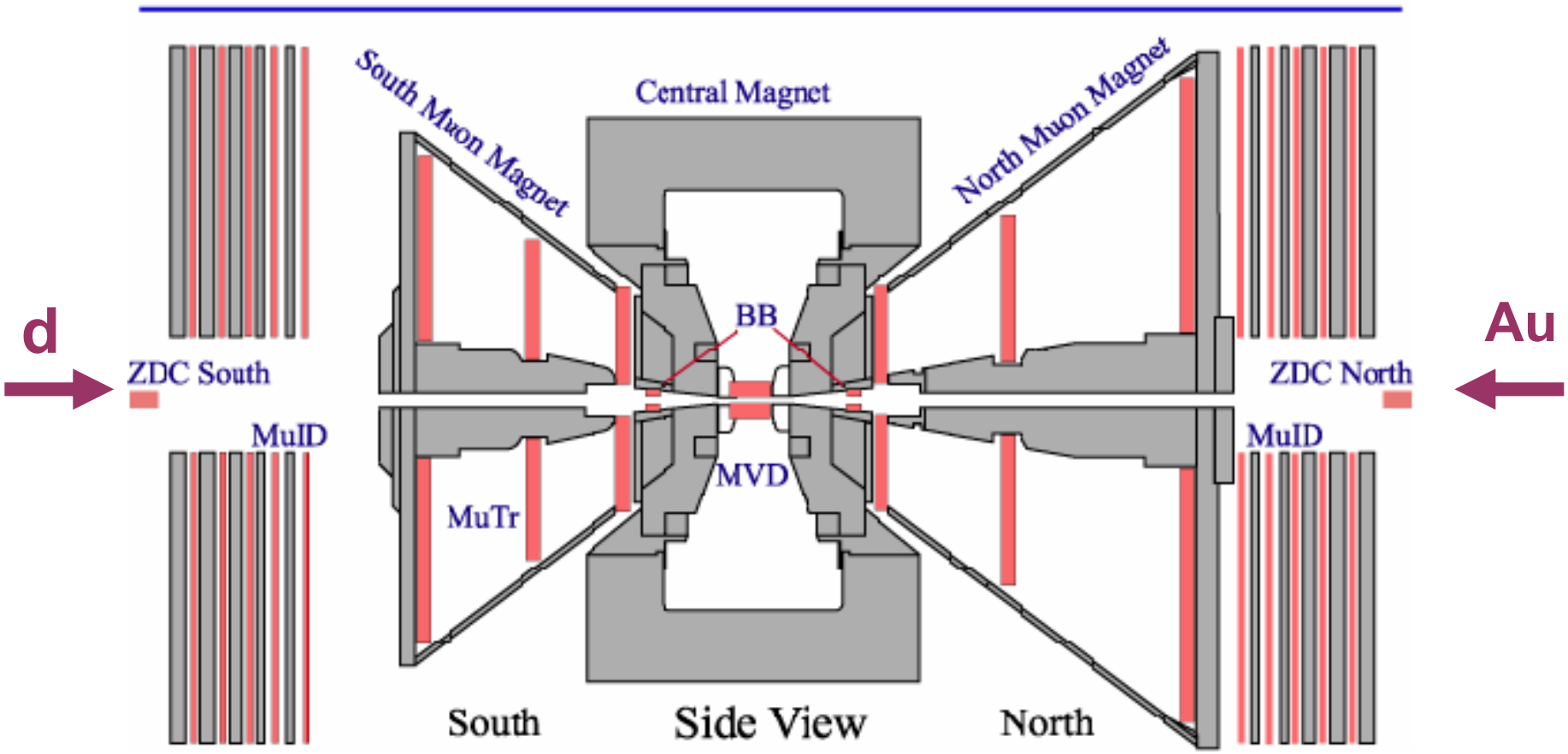
Viewed from J/ψ rest Frame

PHEINX Muon Arm Acceptance

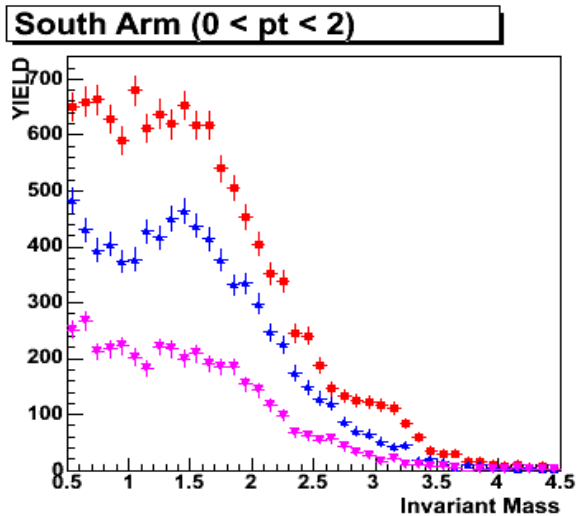


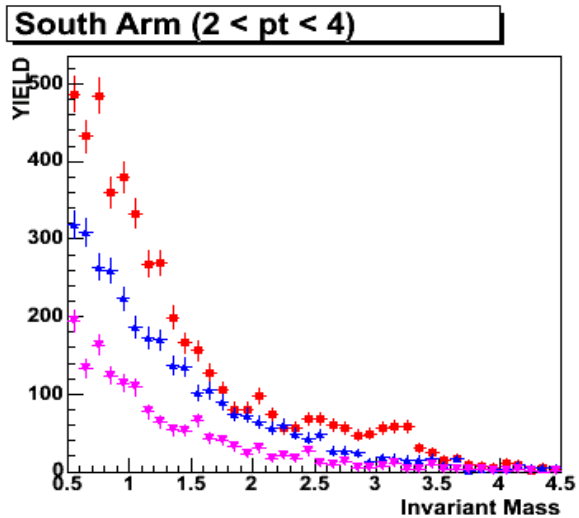
South Arm: $-2.2 < \eta < -1.2$; North Arm: $1.2 < \eta < 2.4$

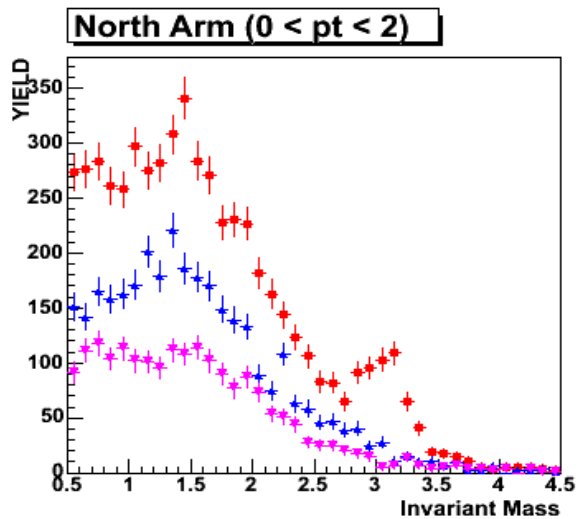
Muon Detector for Run-3

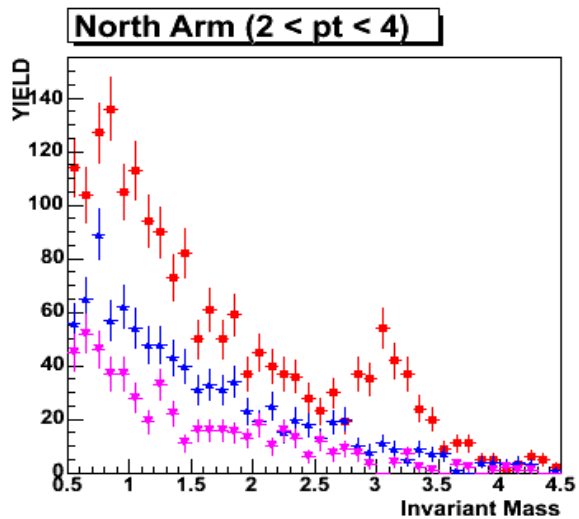


Invariant Mass Spectrum



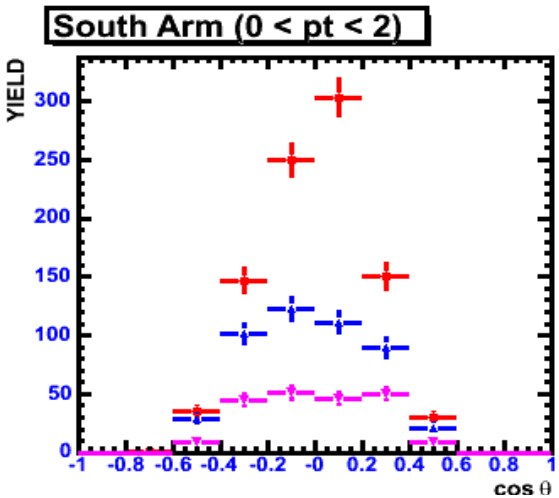


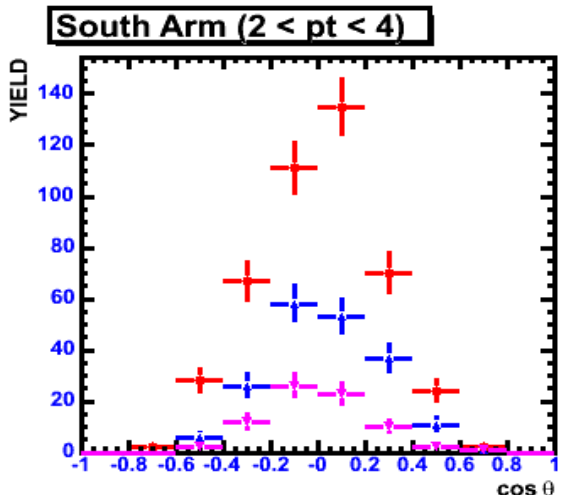


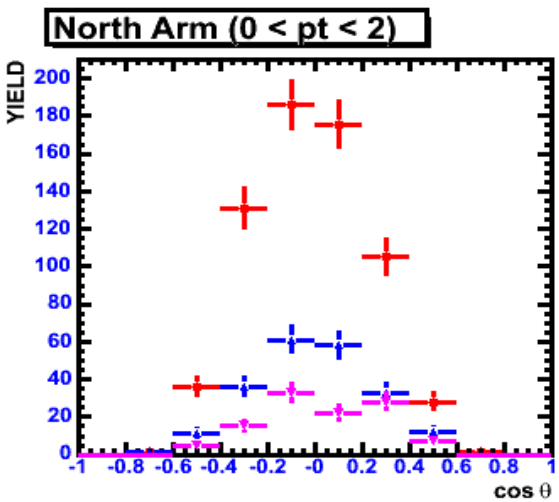


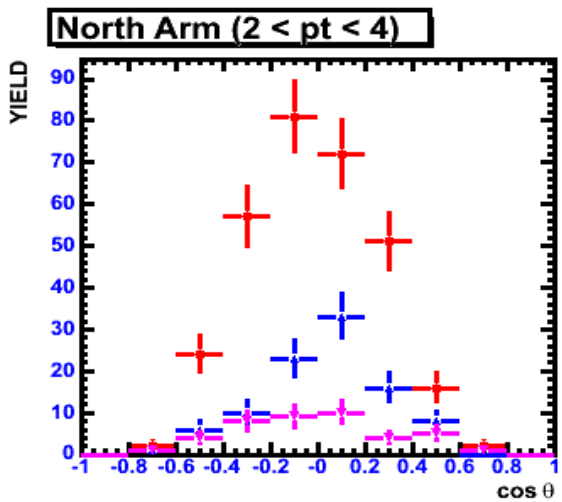
- Unlike sign (+ –)
- ▲ like sign (+ +)
- ▼ like sign (– –)

$\cos\theta_{CS}$ Raw Distribution for Muon Pairs







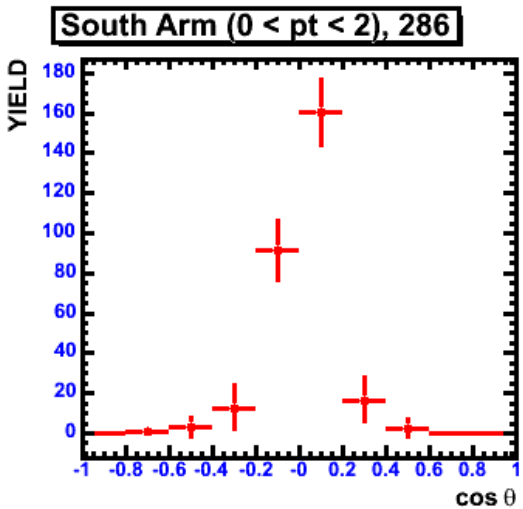


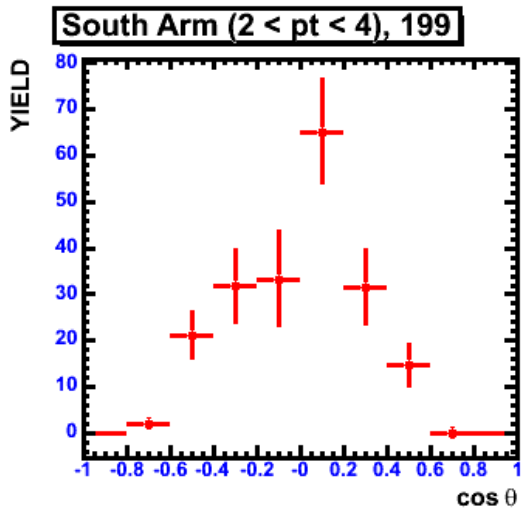
- Unlike sign (+ –)
- ▲ like sign (+ +)
- ▼ like sign (– –)

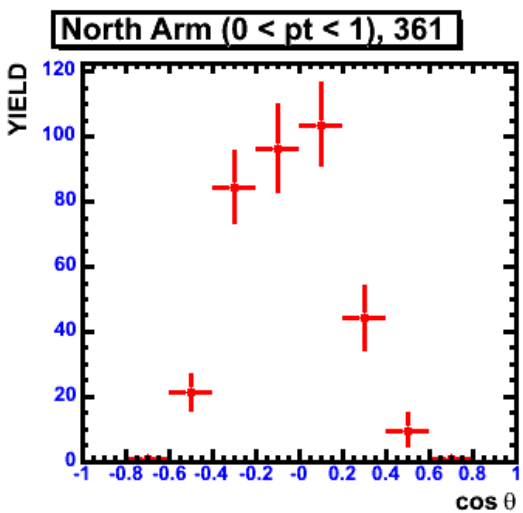
$2.65 < M_{\mu^+\mu^-} < 3.73$ GeV

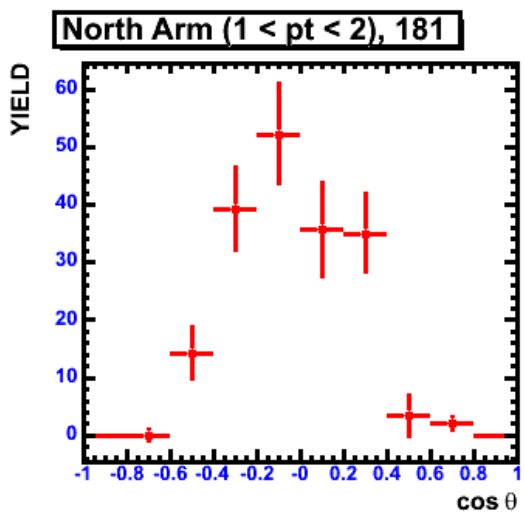
$p_T > 0.5$ GeV

Background Subtracted Raw $\cos\theta_{CS}$ Distribution









Background Subtraction:

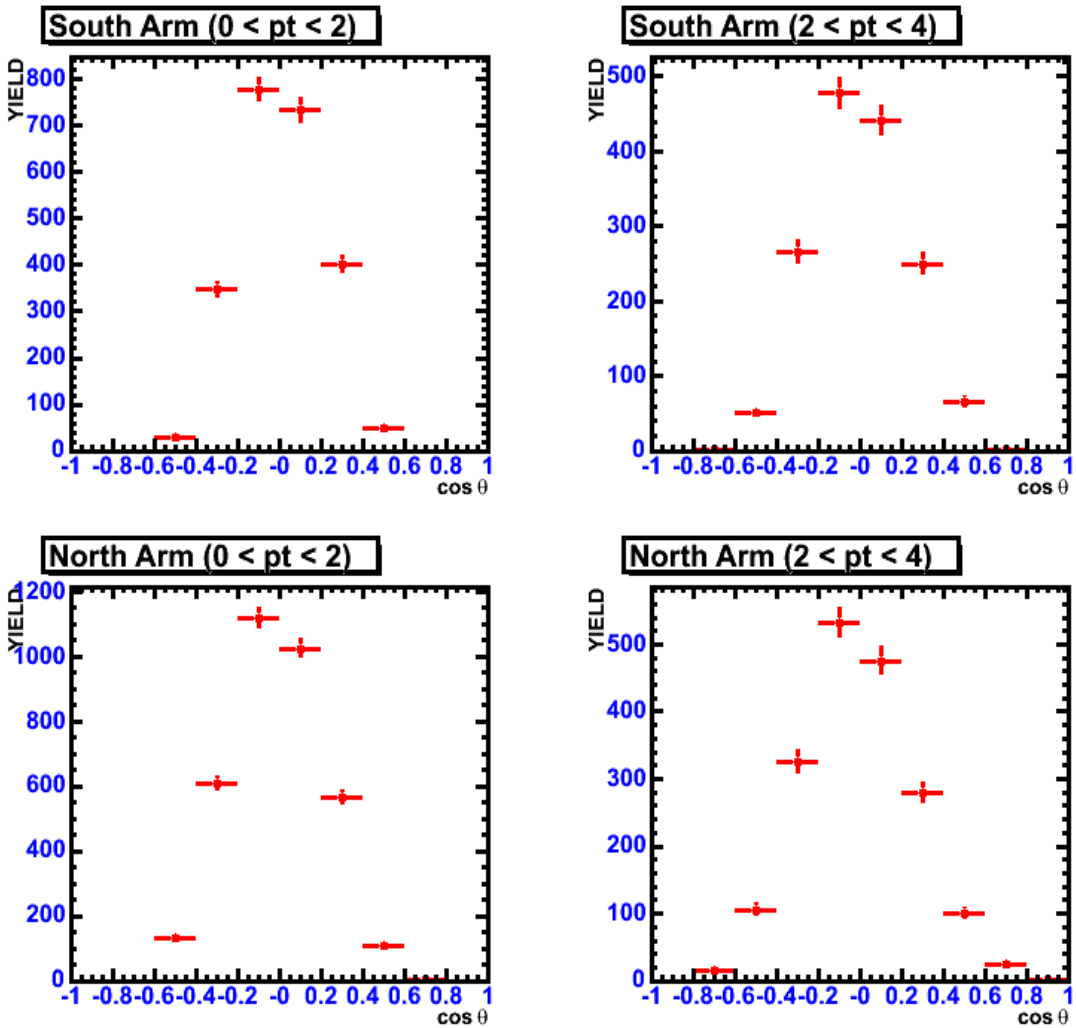
Two p_T bins from 0 to 4 GeV

$$N = N^{+-} - 2\times\sqrt{N^{++}\times N^{--}}$$

Acceptance Correction (Two-Stage Simulation)

- Generate first set of Monte Carlo events with flat p_T, x_F and flat $\cos\theta_{CS}$ distribution. These events were processed with the complete PHENIX simulation chain.
- Extract a correlated p_T and x_F distribution from the reconstructed J/ψ, which provides the correlated detector acceptance correction for J/ψ's p_T and x_F distribution.
- This 2D distribution was then used to extract p_T and x_F distribution from real data.
- The second set of Monte Carlo events were generated with a flat $\cos\theta_{CS}$ distribution and the correlated p_T and x_F distribution obtained from the first step and MC2 events were also processes with the whole PHENIX offline analysis chain.
- All reconstructed J/ψ events were used to calculate the final acceptance correction for $\cos\theta_{CS}$ distribution.

$\cos\theta_{CS}$ Distribution from Two-Stage Simulation

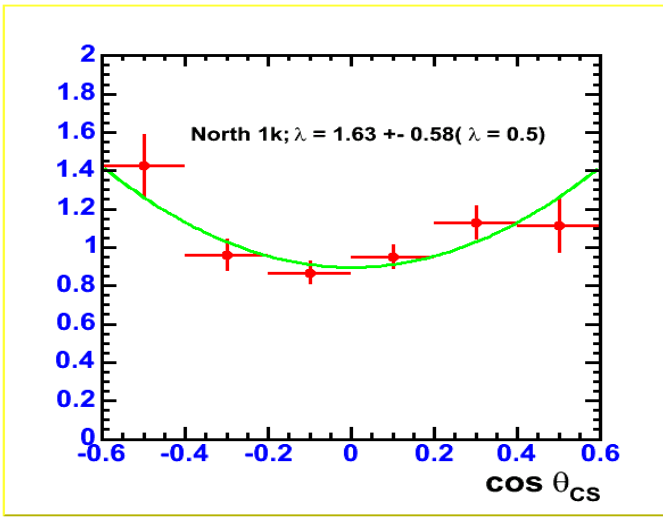


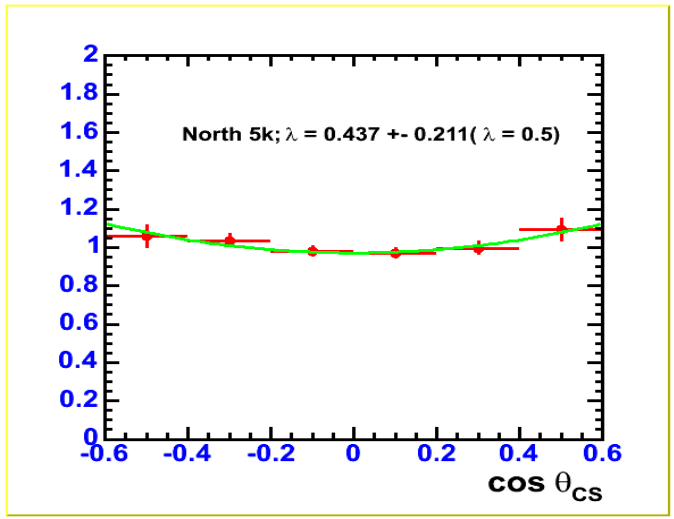
How Many J/ψ We Need for the Polarization Study

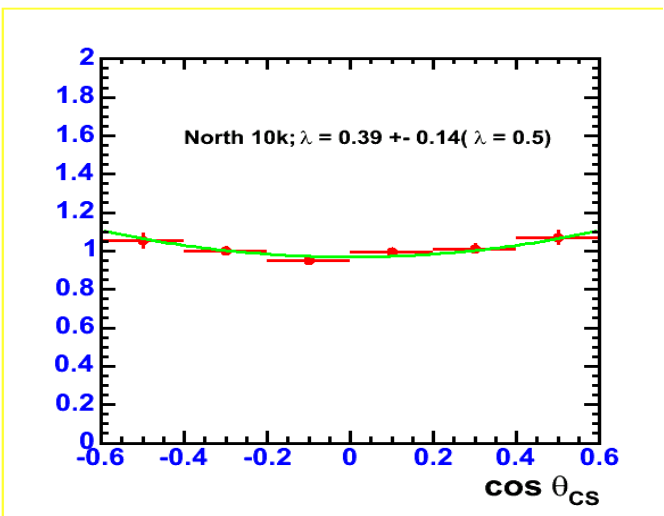
Test Procedure

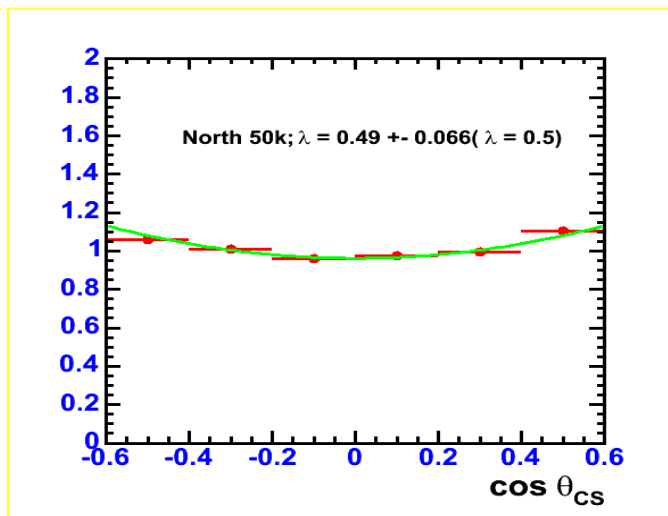
- Generate given number of fake data points with a known λ value and Gaussian p_T and x_F distribution.
- Apply the two stage acceptance correction assuming perfect detector.
- Compare the statistical errors as a function of the given number of fake J/ψ input.

Statistics Error Study for Extracting λ









Input $\lambda = 0.5$

Uncertainty estimation:

- **1K: +/- 0.58**
- **5K: +/- 0.21**
- **10k: +/- 0.14**
- **50k: +/- 0.07**

Summary

- Presented raw angular distribution of PHENIX Run3 d-Au data.
- Developed the procedure of background subtraction and acceptance correction for PHENIX data.
- PHENIX detector has the unique ability to study J/ψ polarization, but we need to collect more J/ψ statistics.
- From a simple Monte Carlo simulation, we estimated that about 5k J/ψ events will be needed in each p_T and x_F bins to achieve a reasonable precision for the polarization parameter λ.